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TOWARDS A MEASUREMENT OF ϕ_3

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Results on the decays $B^- \rightarrow D_{CP}K^-$, $\bar{B}^0 \rightarrow D^{(*)0}\bar{K}^{(*)0}$, $B^0 \rightarrow D^{*\mp}\pi^\pm$ and their charge conjugates using data collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric e^+e^- storage ring are reported. The implications for the determination of the weak phase ϕ_3 are discussed.

1 $B^- \rightarrow D_{CP}K^-$

The extraction of ϕ_3 ¹, an angle of the Kobayashi-Maskawa triangle², is a challenging measurement even with modern high luminosity B factories. Recent theoretical work on B meson dynamics has demonstrated the direct accessibility of ϕ_3 using the process $B^- \rightarrow DK^-$ ^{3,4}. If the D^0 is reconstructed as a CP eigenstate, the $b \rightarrow c$ and $b \rightarrow u$ processes interfere. This interference leads to direct CP violation as well as a characteristic pattern of branching fractions. However, the branching fractions for D meson decay modes to CP eigenstates are only of order 1 %. Since CP violation through interference is expected to be small, a large number of B decays is needed to extract ϕ_3 . Assuming the absence of $D^0 - \bar{D}^0$ mixing, the observables sensitive to CP violation that are used to extract the angle ϕ_3 ⁵ are,

$$\begin{aligned} \mathcal{A}_{1,2} &\equiv \frac{\mathcal{B}(B^- \rightarrow D_{1,2}K^-) - \mathcal{B}(B^+ \rightarrow D_{1,2}K^+)}{\mathcal{B}(B^- \rightarrow D_{1,2}K^-) + \mathcal{B}(B^+ \rightarrow D_{1,2}K^+)} \\ &= \frac{2r \sin \delta' \sin \phi_3}{1 + r^2 + 2r \cos \delta' \cos \phi_3} \\ \mathcal{R}_{1,2} &\equiv \frac{R^{D_{1,2}}}{R^{D^0}} = 1 + r^2 + 2r \cos \delta' \cos \phi_3 \\ \delta' &= \begin{cases} \delta & \text{for } D_1 \\ \delta + \pi & \text{for } D_2 \end{cases} , \end{aligned}$$

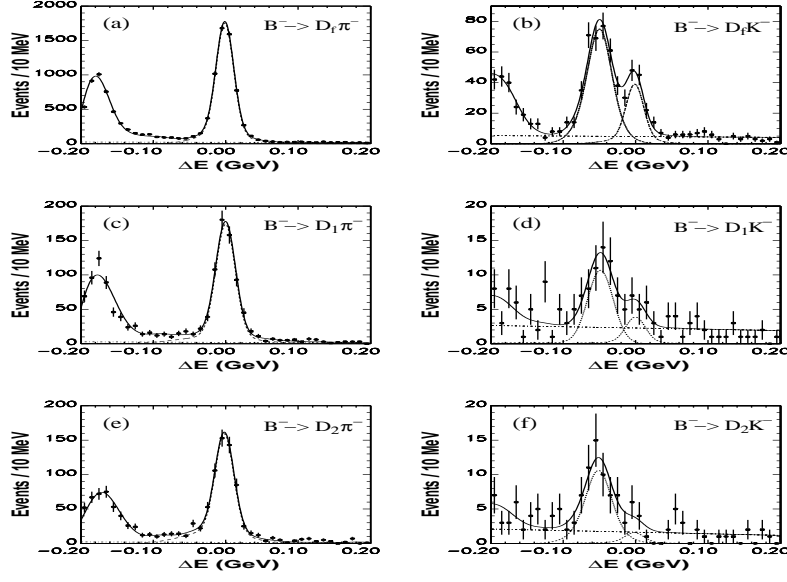


Figure 1: ΔE distributions for (a) $B^- \rightarrow D_f \pi^-$, (b) $B^- \rightarrow D_f K^-$, (c) $B^- \rightarrow D_1 \pi^-$, (d) $B^- \rightarrow D_1 K^-$, (e) $B^- \rightarrow D_2 \pi^-$ and (f) $B^- \rightarrow D_2 K^-$. Points with error bars are the data and the solid lines show the fit results.

Table 1: Signal yields, feed-acrosses and ratios of branching fractions. The errors on R^D are statistical and systematic, respectively.

Mode	$B^- \rightarrow D\pi^-$	$B^- \rightarrow DK^-$	$B \rightarrow D\pi^-$	$R^D = \frac{\mathcal{B}(B^- \rightarrow D^0 K^-)}{\mathcal{B}(B^- \rightarrow D^0 \pi^-)}$
	events	events	feed-across	
$B^- \rightarrow D_f h^-$	6052 ± 88	347.5 ± 21	134.4 ± 14.7	$0.077 \pm 0.005 \pm 0.006$
$B^- \rightarrow D_1 h^-$	683.4 ± 32.8	47.3 ± 8.9	15.6 ± 6.4	$0.093 \pm 0.018 \pm 0.008$
$B^- \rightarrow D_2 h^-$	648.3 ± 31.0	52.4 ± 9.0	6.3 ± 5.0	$0.108 \pm 0.019 \pm 0.007$

where the ratios $R^{D_{1,2}}$ and R^{D^0} are defined as

$$R^{D_{1,2}} = \frac{\mathcal{B}(B^- \rightarrow D_{1,2} K^-) + \mathcal{B}(B^+ \rightarrow D_{1,2} K^+)}{\mathcal{B}(B^- \rightarrow D_{1,2} \pi^-) + \mathcal{B}(B^+ \rightarrow D_{1,2} \pi^+)},$$

$$R^{D^0} = \frac{\mathcal{B}(B^- \rightarrow D^0 K^-) + \mathcal{B}(B^+ \rightarrow \bar{D}^0 K^+)}{\mathcal{B}(B^- \rightarrow D^0 \pi^-) + \mathcal{B}(B^+ \rightarrow \bar{D}^0 \pi^+)},$$

D_1 and D_2 are CP-even and CP-odd eigenstates of the neutral D meson, r denotes a ratio of amplitudes, $r \equiv |A(B^- \rightarrow \bar{D}^0 K^-)/A(B^- \rightarrow D^0 K^-)|$, and δ is their strong phase difference. Note that the asymmetries \mathcal{A}_1 and \mathcal{A}_2 have opposite signs. We reconstruct D^0 mesons in the following decay channels. For the flavor specific mode (denoted by D_f), we use $D^0 \rightarrow K^- \pi^+$ ⁸. For CP = +1 modes, we use $D_1 \rightarrow K^- K^+$ and $\pi^- \pi^+$ while for CP = -1 modes, we use $D_2 \rightarrow$

Table 2: Yields, partial-rate charge asymmetries and 90 % C.L intervals for asymmetries.

Mode	$N(B^+)$	$N(B^-)$	\mathcal{A}_{CP}	90 % C.L
$B^\pm \rightarrow D_f K^\pm$	165.4 ± 14.5	179.6 ± 15	$0.04 \pm 0.06 \pm 0.03$	$-0.07 < \mathcal{A}_f < 0.15$
$B^\pm \rightarrow D_1 K^\pm$	22.1 ± 6.1	25.0 ± 6.5	$0.06 \pm 0.19 \pm 0.04$	$-0.26 < \mathcal{A}_1 < 0.38$
$B^\pm \rightarrow D_2 K^\pm$	29.9 ± 6.5	20.5 ± 5.6	$-0.19 \pm 0.17 \pm 0.05$	$-0.47 < \mathcal{A}_2 < 0.11$

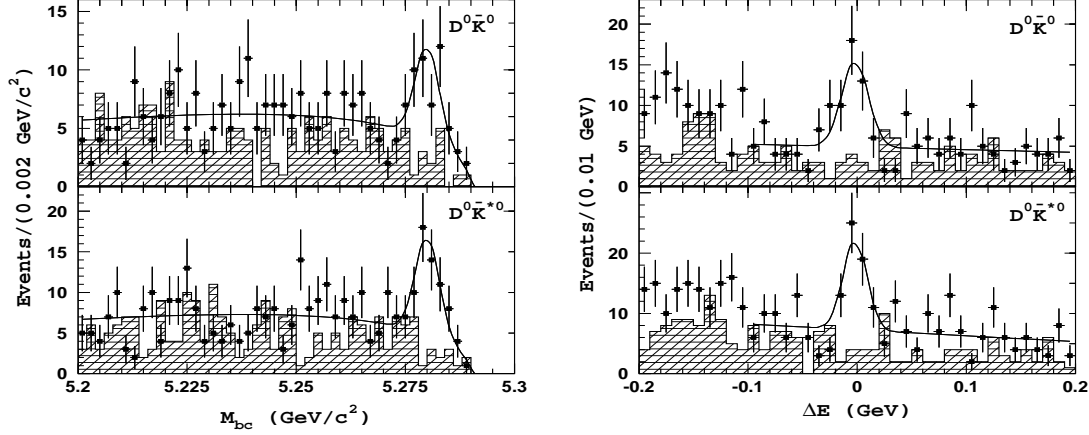


Figure 2: ΔE (left) and M_{bc} (right) distributions for the $\bar{B}^0 \rightarrow D^0 \bar{K}^{(*)0}$ candidates. Points with errors represent the experimental data, hatched histograms show the D^0 mass sidebands and curves are the results of the fits.

Table 3: Fit results, branching fractions or upper limits at 90 % C.L and statistical significances for $\bar{B}^0 \rightarrow \bar{D}^{(*)0} \bar{K}^{(*)0}$.

Mode	ΔE yield	M_{bc} yield	$\mathcal{B}(10^{-5})$	significance
$\bar{B}^0 \rightarrow D^0 \bar{K}^0$	$31.5^{+8.2}_{-7.6}$	$27.0^{+7.6}_{-6.9}$	$5.0^{+1.3}_{-1.2} \pm 0.6$	5.1σ
$\bar{B}^0 \rightarrow D^0 \bar{K}^{*0}$	$41.2^{+9.0}_{-8.5}$	$41.0^{+8.7}_{-8.1}$	$4.8^{+1.1}_{-1.0} \pm 0.5$	5.6σ
$\bar{B}^0 \rightarrow D^{*0} \bar{K}^0$	$4.2^{+3.7}_{-3.0}$	$2.7^{+3.0}_{-2.4}$	< 6.6	1.4σ
$\bar{B}^0 \rightarrow D^{*0} \bar{K}^{*0}$	$6.1^{+5.2}_{-4.5}$	$8.6^{+4.2}_{-3.6}$	< 6.9	1.4σ
$\bar{B}^0 \rightarrow \bar{D}^0 \bar{K}^{*0}$	$1.4^{+8.2}_{-7.6}$	$9.2^{+7.7}_{-7.2}$	< 1.8	—
$\bar{B}^0 \rightarrow \bar{D}^{*0} \bar{K}^{*0}$	$1.2^{+4.1}_{-3.6}$	$0.0^{+3.9}_{-3.2}$	< 4.0	—

$K_S^0 \pi^0$, $K_S^0 \phi$, $K_S^0 \omega$, $K_S^0 \eta$ and $K_S^0 \eta'$. We combine the D^0 and π^-/K^- candidates (denoted by h) to form B candidates. The signal is identified by two kinematic variables calculated in the center-of-mass (c.m.) frame. The first is the beam-energy constrained mass, $M_{bc} = \sqrt{E_{\text{beam}}^2 - |\vec{p}_D + \vec{p}_h|^2}$, where \vec{p}_D and \vec{p}_h are the momenta of D^0 and K^-/π^- candidates and E_{beam} is the beam energy in the c.m. frame. The second is the energy difference, $\Delta E = E_D + E_h - E_{\text{beam}}$, where E_D is the energy of the D^0 candidate, E_h is the energy of the K^-/π^- candidate calculated from the measured momentum and assuming the pion mass, $E_h = \sqrt{|\vec{p}_h|^2 + m_\pi^2}$. With this definition, real $B^- \rightarrow D^0 \pi^-$ events peak at $\Delta E = 0$ even when they are misidentified as $B^- \rightarrow D^0 K^-$, while $B^- \rightarrow D^0 K^-$ events peak around $\Delta E = -49 \text{ MeV}$ ⁹. The signal yields are extracted from a fit to the ΔE distribution in the region $5.27 \text{ GeV}/c^2 < M_{bc} < 5.29 \text{ GeV}/c^2$. The fit results, using 78 fb^{-1} data, are shown in Fig. 1. The signal yields and CP asymmetries are shown in Table 1 and Table 2.

2 $\bar{B}^0 \rightarrow D^{(*)0} \bar{K}^0$ and $\bar{B}^0 \rightarrow D^{(*)0} \bar{K}^{*0}$

The two-body decays of the above type, which occur via tree-level diagrams, can be used to test the factorization hypothesis. Precise measurements of the decay rates allow one to construct the isospin relation between the transition amplitudes and determine the relevant strong and weak phase. The modes $\bar{B}^0 \rightarrow D^0 \bar{K}^{*0}$, $\bar{B}^0 \rightarrow \bar{D}^0 \bar{K}^{*0}$ and $\bar{B}^0 \rightarrow D_{CP} \bar{K}^{*0}$ decays also allow a measurement of the angle ϕ_3 . We reconstruct D^0 mesons in the decay channels: $K^- \pi^+$, $K^- \pi^+ \pi^0$ and $K^- \pi^+ \pi^- \pi^+$, using a requirement that the invariant mass be within $20 \text{ MeV}/c^2$,

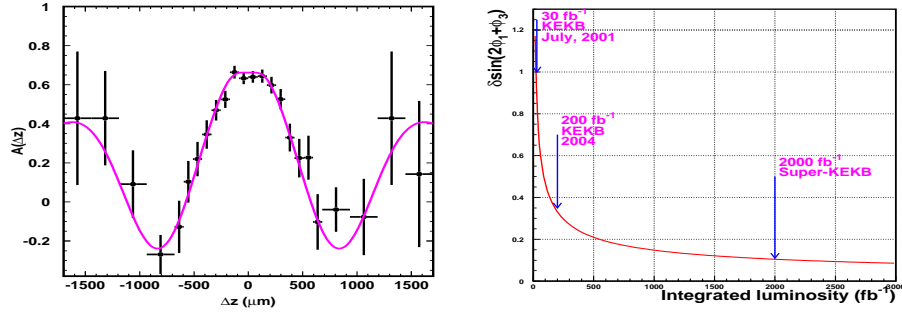


Figure 3: (Left) Distribution of the asymmetry, $A(\Delta z)$, as a function of Δz for the data with the fit curve overlaid. (Right) Error on $\sin(2\phi_1 + \phi_3)$, as a function of integrated luminosity.

15 MeV/c^2 and 25 MeV/c^2 of the nominal D^0 mass, respectively. In each channel we further define a D^0 mass sideband region, with width twice that of signal region. For the π^0 from the $D^0 \rightarrow K^-\pi^+\pi^0$ decay, we require that its momentum in the CM frame be greater than 0.4 GeV/c in order to reduce combinatorial background. D^{*0} mesons are reconstructed in the $D^{*0} \rightarrow D^0\pi^0$ decay mode. The mass difference between D^{*0} and D^0 candidates is required to be within 4 MeV/c^2 of the expected value. \bar{K}^{*0} candidates are reconstructed from $K^-\pi^+$ pairs with an invariant mass within 50 MeV/c^2 of the nominal \bar{K}^{*0} mass. We then combine $D^{(*)0}$ candidates with K_S^0 or \bar{K}^{*0} to form B mesons. For the final result using 78 fb^{-1} data, a simultaneous fit to the ΔE distributions for the three D^0 decay channels taking into account the corresponding detection efficiencies¹⁰. The fit result is shown in Fig. 2. The signal yields from the fitting and the branching fractions are shown in Table 3.

3 $B^0 - \bar{B}^0$ mixing with $B^0(\bar{B}^0) \rightarrow D^{*\mp}\pi^\pm$ partial reconstruction.

Since both Cabibbo-favoured ($B^0 \rightarrow D^{*-}\pi^+$) and Cabibbo-suppressed ($\bar{B}^0 \rightarrow D^{*-}\pi^+$) decays contribute to the $D^{*-}\pi^+$ final state, a time-dependent analysis can be used to measure $\sin(2\phi_1 + \phi_3)$. Since the ratio of amplitudes is expected to be small (~ 0.02), the CP asymmetry will be hard to observe, but may be possible since the $B^0 \rightarrow D^{*-}\pi^+$ decay rate is fairly large. A first step towards this measurement is the extraction of the mixing parameter Δm_d from $B^0 \rightarrow D^{*-}\pi^+$.

We use events with a partially reconstructed $B^0(\bar{B}^0) \rightarrow D^{*\mp}\pi^\pm$ candidates and where the flavor of the accompanying B meson is identified by the charge of the lepton from a $B^0(\bar{B}^0) \rightarrow X^\mp l^\pm \nu$ decay. The proper-time difference between the two B mesons is determined from the distance between the two decay vertices (ΔZ). From a simultaneous fit to the proper-time distributions for the same flavor(SF) and opposite flavor(OF) event samples, we measure the mass difference between the two mass eigenstates of the neutral B meson to be $\Delta m_d = (0.509 \pm 0.017(\text{stat}) \pm 0.020(\text{sys}))ps^{-1}$. The result is obtained using 29.1 fb^{-1} data collected with Belle detector at KEKB. This is the first direct measurement of Δm_d using the technique of partial reconstruction. Fig. 3(left) shows the mixing asymmetry $A(\Delta Z)$ as a function of ΔZ where

$$A(\Delta Z) \equiv \frac{N^{OF}(\Delta Z) - N^{SF}(\Delta Z)}{N^{OF}(\Delta Z) + N^{SF}(\Delta Z)} \quad (1)$$

where $N(\Delta Z)$ is the yield of the signal candidates as a function ΔZ ¹¹. This method can be extended to measure the weak angle $2\phi_1 + \phi_3$. The expected statistical error on $\sin(2\phi_1 + \phi_3)$ is estimated from a large Monte Carlo sample that does not include the effects of backgrounds and mistagging is shown in Fig. 3(right). The expected sensitivity is around 0.35 at 200 fb^{-1} .

Acknowledgments

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References

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